University of Strathclyde

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Video Processing Analysis for Non-Invasive Fatigue Detection and Quantification

By

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Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of a degree.

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Abstract

Fatigue is a common symptom of weakness either physically or mentally. These symptoms may led to a drop in motivation, weakened sensitivity, slowing of responsiveness and inability to give full attention. All of these problems can cause adverse effects, such as accidents, especially those that require full attention as drivers of vehicles, and rail operators, the pilot of an aircraft or ship operators. This research investigates systems to detect and quantify the signs of fatigue using non-invasive facial analytics.

There are four main algorithms that represent the major contribution from the PhD research. These algorithms encompass facial fatigue detection and quantification system as a whole. Firstly, a new technique to detect the face is introduced. This face detection algorithm is an affiliation of colour skin segmentation technique, connected component of binary image usage, and learning machine algorithm. The introduced face detection algorithm is able to reduce the false positive detection rate by a very significant margin. For the facial fatigue detection and quantification, the major fatigue signs features are from the eye activity. A new algorithm called the , Interdependence and Adaptive Scale Mean Shift (IASMS) is presented. The IASMS is able to quantify the state of eye as well as to track non-rigid eye movement. IASMS integrates the mean shift tracking algorithm with an adaptive scale scheme, which is used to track the iris and quantify the iris size. The IASMS is associated with face detection algorithm, image enhanced scheme, eye open detection technique and iris detection method in the initialisation process. This proposed method is able to quantify the eye activities that represent the blink rate and the duration of eye closure.

The third contribution is yawning analysis algorithm. Commonly yawning is detected based on a wide mouth opening. Frequently however this approach is thwarted by the common human reaction to hand-cover the mouth during yawning. In this

research, a new approach to analyse yawning which takes into account the covered mouth is introduced. This algorithm combines with a new technique of mouth opening measurements, covered mouth detection, and facial distortion (wrinkles) detection. By using this proposed method, yawning is still able to detect even though the mouth is covered.

In order to have reliable results from the testing and evaluating of the developed fatigue detection algorithm, the real signs of fatigue are required. This research develops a recorded face activities database of the people that experience fatigue. This fatigue database is called as the Strathclyde Fatigue Facial (SFF). To induce the fatigue signs, ethically approved sleep deprivation experiments were carried out. In these experiments twenty participants, and four sessions were undertaken, which the participant has to deprive their sleep in 0, 3, 5, and 8 hours. The participants were subsequently requested to carry out 5 cognitive tasks that are related to the sleep loss.

The last contribution of this research is a technique to recognise the fatigue signs. The existing fatigue detection system is based on single classification. However, this work presents a new approach for fatigue recognition which the fatigue is classified into levels. The levels of fatigue are justified based on the sleep deprivation stages where the SFF database is fully used for training, testing and evaluation of the developed fatigue recognition algorithm. This fatigue recognition algorithm is then integrated into a Fatigue Monitoring Tool (FMT) platform. This FMT has been used to test the participant that carried out the tasks as ship crew in shipping bridge simulator.

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Abbreviations

AAM	Active Appearance Model
AdaBoost	Adaptive Boosting
AECS	Average Eye Closure Speed
ARRB	Australian Road Research Board
ASM	Active Shape Model
ASTiD	Advisory System for Tired Driver
AU	Action Unit
AVMED	Institute of Aviation Medicine
BN	Bayesian Network
CAMSHIFT	Continuously Adaptive Mean Shift
CAS	Circadian Alertness Simulator
CAS-PEAL	Chinese Academic of Science - Pose, Expression, Accessories, and Lighting
CASIA	Chinese Academic of Science
CeSIP	Centre for excellence in Signal and Image Processing University of Strathclyde
CMU	Carnegie Mellon University
COPD	Chronic obstructive pulmonary disease
DFM	driver fatigue monitoring system
ECG	Electrocardiograph
ED	Distance between the centre of eyes
EDVTCS	Engine Driver Vigilance Telemetric Control System
EEG	Electroencephalography
EOG	Electrooculography

EMD	Distance between centre of mouth and the middle point between eyes
faceLAB^{TM}	Face Laboratory
FAID	Fatigue Audit Interdyne
FACS	Facial Action Coding System
FER	Focus of Eye Region
FERET	Facial Recognition Technology
FFS	Forward Features Selection
FMR	Focus Mouth Region
FMT	Fatigue Monitoring Tool
FRMS	Fatigue Risk Management System
FSI	Flag State Implementation
FWR	Focus Wrinkles Region
GUI	Graphical user interface
HIV	Human immunodeficiency virus
HOG	Histograms of Oriented Gradients
HMM	Hidden Markov Model
HSI	Hue Saturation Intensity
HSV	Hue Saturation Value
IASMS	Interdependence and Adaptive Scale Mean Shift
ICAO	International Civil Aviation Organization
ICE	Iris Challenge Evaluation
IMO	International Maritime Organisation
IR	Infrared
ISM	International Safety Management
Lab	Laboratory
LBP	Local Binary patterns
LDA	Linear Discrimination Analysis
LED	Light Emitting Diode
MIT	Massachusetts Institute of Technology

MLR	Multinomial Ridge Regression
MMU	Malaysia Multimedia University
mo	mount opening
NIR	Near Infrared
NN	Neural Network
PCA	Principal Component Analysis
PERCLOS	Prominent technique
PIE	CMU Pose, Illumination, and Expression
PsyKE	Psychology Knowledge Exchange & Enterprise Unit University of Strathclyde, and Glasgow Sleep Centre
PVT	Psychomotor vigilance task
RAAF	Royal Australian Air Force
RGB	Red Green Blue
RLBP	Regional Local Binary Pattern
SAD	Sum of Absolute Difference
SAFE	System for Air Crew Fatigue Evaluation
SART	Sustained Attention to Response Task
SFF	Strathclyde Facial Fatigue
SGLD	Second order statistical features
SMS	Safety Management System
SURF	Speed Up Robust Features
SVM	Support Vector Machine
3D	Three dimensional
TPMA	Three Process Model of Alertness
UBIRIS	Irises database from University of Beira Interior
UEC	University Ethic Committee of University of Strathclyde
YAWN	Yawning
YcbCr	Luminance and chroma component colour space
YR	Yawn rate
ZJU	Zhejiang University

List of Symbols

δ	Delta
θ	Theta
α	Alpha
f	PERCLOS curve over a certain period
t_1	The time the eye is closed for only 20%
t_2	The time when the eyes are 20% from completely closed
t_3	The times from eye open to eye 20% open (after being closed)
t_4	The times from eye open to eye 80% open (after being closed)
r	red
g	green
b	blue
c_b	Blue different chroma component
c_r	Red different chroma component
hue	Properties of colour
y_{min}	Minimum y axis
y_{max}	Maximum y axis
x_{min}	Minimum x axis
x_{max}	Maximum x axis
R	radius
ϵ	epsilon

$B(x, y)$	A bounding rectangle
sm	Small region of pixels
bg	Large region of pixels
$g'(x,y)$	Enhanced input image
$g(x,y)$	Input image
$Gl_{\min}$	The minimum input image intensities
$Gl_{\max}$	The maximum input image intensities
$Gl'_{\min}$	The transformed minimum input image intensities
$Gl'_{\max}$	The transformed minimum input image intensities
H_i	The cumulative histogram
X	The intensity value
aT	The adaptive threshold
$P_{\min}$	The minimum pixel value
$P_{\max}$	The maximum pixel value
sr	The aspect ratio of the bounding box shape
hbb	Height of then bounding box shape
wbb	Width of the bounding box shape
r	The iris radius
x_0	The coordinate of the iris centre in the *x*-direction
y_0	The coordinate of the iris centre in the *y*-direction
$I(x,y)$	The input iris image
$G_\sigma(r)$	The Gaussian function

$\hat{q} = \{\hat{q}_u\}_{u=1...m}$	The probability of the colour histogram of the iris
M	The number of histogram bins
x_i	Normalised pixel location from 1 to n with the target iris centred at 0
δ	Kronecker delta function
$b(x_i)$	The bin for pixel x_i
k	The Epanechnikov kernel function
C	Normalisation constant
$\hat{p}_u(y)$	The probability of colour histogram of the target iris candidate model
Y	Centre position of the current frame
H	Radius of weighting kernel
C_h	The normalisation constant
$d(y)$	The centre of the iris
$\hat{p}(y)$	Estimation of the Bhattacharyya coefficient
y_1	New location targeted iris
w_i	The weight
M_{00}	Zeroth moment of the region
M_{10}, M_{01}, M_{11}	First-order moments
$I(x, y)$	Probability pixel value within the object region in x and y range
x_c, y_c	The centroid point of the region
M_{20}, M_{02}	Second-order moments
μ_{20}, μ_{02}, μ_{11}	Rotation of ellipse
θ	Degree of orientation of the ellipse

a, b	The semi-major axis of the ellipse
A	Area of region computed from the zeroth moment
l_1	Length 1
l_2	Length 2
C_r	Centre point of the right eye
C_l	Centre point of the left eye
D_e	Distance between centre points of the irises
I_{FER}	Size of the FER
I_{SAD}	Sum of Absolute Difference (SAD) value of FER in between two frames
I_{SAD}	The normalise value of SAD
W	Width of FER
H	Height of FER
T_{AOi}	Threshold value of the iris area
Rem	The ratio of ED and EMD distances
x_1	Centre of right eye
x_2	Centre of left eye
ml	The measured length of mouth
mh	The height of the mouth
YR	The ratio of *hl* to height of FMR
$LBP_{P,R}(x_c, y_c)$	The result of Local Binary Pattern
i_c, i_p	Gray level values of the central pixel
	Surrounding pixels in the circle neighborhood

P	Surrounding pixels
R	Radius
ri	Rotational invariant
$s(x)$	Function binary LBP
$u2$	Uniform pattern
$riu2$	rotational invariant pattern with uniform pattern
$ROR(x,i)$	Circular bitwise right shift on the *P*-bit number x with i time
$LBP^{u2}_{(P,R)}$	LBP uniform pattern
$LBP^{riu2}_{(P,R)}$	Combination of rotational invariant pattern with uniform pattern
G_x	The gradient for the horizontal directions
G_y	The gradient for the vertical directions
FWR_{SAD}	Sum of the absolute values *FWR*
$Normalised\, FWR_{SAD}$	The normalise value of SAD
BR	Blink rate
T_{tec}	Total time of eye closed
A_{tec}	Average time of eye closed
Ac_{BR}	Accumulated *BR*
Ac_{NTtec}	Accumulated Normalised T_{tec}
$\mathrm{Ac}_{\mathrm{Atec}}$	Acculumated A_{tec}

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